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COMPLETE SPECIFICATION

Apparatus for the Production of Energy by Nuclear Fission

We, CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, formerly known as La Caisse Nationale de la Recherche Scientifique, an official and autonomous organisation created by decree of the Government of the French Republic, of 13, Quai d'Orsay, Paris, France, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to an apparatus for the production of energy by disintegration of atomic nuclei.

It is known that the absorption of a neutron by an uranium nucleus can lead to the fission of the latter, this phenomenon being associated with the liberation of energy and the emission of new neutrons the number of which is on the average greater than unity. A fraction of these neutrons can in their turn produce fission when colliding with further uranium nuclei and in this way further fissions could go on, their number increasing in geometric progression and liberating a considerable amount of energy.

It has been found that if such a phenomenon could be performed inside a limited mass of uranium (or of a uranium compound or of a mixture containing uranium) it would be possible to extract from this mass the energy liberated in this way by chains of successive fissions and to use this energy for industrial purposes. But one meets at once a primary difficulty: since these chains can branch in an unlimited way the reaction may become explosive and this would considerably limit the possibilities of using the mass of uranium in question as a controllable source of industrial energy.

It has, therefore, been attempted to control the liberation of energy by preventing its becoming explosive. The idea has been conceived of reducing the velocity of all or a part of the liberated neutrons, thus obtaining slow neutrons in approximate thermal equilibrium with the whole system of particles. This reduction of the velocity provides in itself a method of stabilisation, since the probability of a neutron causing fission decreases with increasing velocity (the faster neutrons being more rapidly lost through the uranium surface) and therefore decreases with increasing temperature.

By this method, the chains can develop until a sufficient amount of energy is liberated and then be automatically interrupted or limited, thus avoiding an explosive development of the reaction.

It is possible to succeed in this way in liberating in the mass of uranium in question the energy which it can provide by fission and to use it for industrial purposes.

In order to reduce the velocity of all or part of the neutrons, helium or deuterium, the latter being in an elementary or combined state, is introduced inside the mass of uranium, the distribution being not necessarily homogeneous.

A special advantage of the use of deuterium or helium for slowing down is the decrease of the fraction of neutrons which are absorbed by resonance in the uranium and which may thus be lost for the chain reaction, which may not be able to maintain itself.

These slowing down elements may be introduced in a liquid or gaseous or solid state (as a powder, for instance).

They can be mixed in a more or less thorough way with the uranium or the uranium compound and the mixture can be obtained by any known method.

One can, for instance, mix a uranium compound in the form of a powder with a liquid or gaseous hydrogenated compound, this compound being, for instance, a hydrocarbon, water, steam, a gas containing hydrogen the hydroxide or hydride of a metal.

When the deuterium or helium which is introduced into the mass of uranium is a gas or a vapour, it is possible to intro-

duce it if desired under pressure, for instance in order to maintain the concentration of this product in spite of the increase of temperature.

The proportion in which the deuterium or helium element is introduced must not be so great as to prevent the persistance of developement of the chain reaction.

A formula enabling an estimation of this quantity will be given further on.

Maximum values which must not be exceeded for the quantities of elements introduced for slowing down (deuterium or helium) can be estimated approximately in the following way:—

If n is the average number of neutrons liberated by one nuclear fission of uranium, P the product of the concentration of uranium (number of atoms per volume unit) and the effective cross section of the uranium nucleus for fission capture (which cross section varies approximately inversely proportionally to the neutron velocity, A the sum of the corresponding products taken for all sorts of nuclei present in the device and whose cross section for the absorption of thermal neutrons varies approximately inversely proportionally to the neutron velocity the formula:—

$$n^1 = n \frac{P}{A} > 1$$

is obtained from which the maximum allowable concentration may be found.

It has been seen that an increase of the temperature decreases n^1 and will cause it to vary from a value above unity to a value lower than this.

In practice, one could start with concentrations greater than those given by the above relation (for one or for several constituents and decrease progressively the said concentrations in order to obtain the desired operation of the system.

Therefore, the apparatus for the production of energy according to the invention will consist of a mass of uranium or uranium compounds containing on a homogeneous or heterogeneous distribution an element for the slowing down of neutrons; the whole system can be enclosed in an envelope.

Owing to the combined action of these two elements inside the system the stabilisation of this reaction will be established automatically and without the possibility of producing an explosion when the reaction has started, i.e. when the absorption of neutrons by the uranium has started to produce energy.

Progressively, as this energy is produced, it will be extracted for industrial purposes, as will be seen later on.

When the production of energy is superior to its extraction the temperature will increase until it attains and exceeds slightly the predetermined temperature of stabilisation. At once the branching of the reaction chains will be reduced and the temperature will decrease and become again equal and slightly less than the temperature of stabilisation. The branching of the chains will then increase again with consequent rise in temperature and so on.

The starting of the reaction (or its starting again after the temperature has fallen below the temperature of stabilisation) can be effected by the sole action of cosmic radiation or by neutrons remaining in the system (in the case of restarting) or by the action of a source of neutrons located in the system or near the system and consisting, for example, of a mass of radium mixed with beryllium or by the introduction into the system of an element such as beryllium which will emit neutrons under the influence of the radiation of uranium or by neutrons emitted with a time lag by substances formed in preceding transformations.

The operation of the system for the production of energy can be stopped by dislocating the mass of uranium (consisting for instance of two hemispheres which will be separated from one another) or by increasing (or decreasing) the quantity of elements used for slowing down neutrons.

It should be mentioned now that the operation of the device such as it has just been explained is also influenced by the whole quantity of uranium or uranium compounds which is used.

As a matter of fact, there exists—all the other conditions remaining unchanged—a critical value for the mass of the device below which the branching of the chains will no longer be unlimited. Since science now has at its disposal means for measuring the multiplication of neutrons, it will be easy to estimate the value of the critical mass by progressive experiments.

This critical mass can be decreased by surrounding the device with diffusing substances in layers more or less thick and forming, for example, a diffusing envelope which completely or incompletely surrounds the mass. These layers have the effect of reflecting escaping neutrons back into the mass and thus rendering escape more difficult.

This envelope—by reflecting into the mass of uranium neutrons which without this would leave it or which have been produced in the envelope—facilitates the formation of chains.

These diffusing substances may consist of iron, of lead, of beryllium, of calcium

carbonate or other elements and may attain, for instance, a thickness of several decimetres.

Furthermore, the critical mass can be decreased by increasing the density of the substances of which it consists.

For a given composition the critical mass is, as a matter of fact, proportional to the inverse of the square of the density.

In order to increase the density one will, therefore, use substances of a high density (metallic uranium, which may be or not be carburetted, uranium carbide, or the like).

It is also of interest to use, for slowing down, substances of a high density.

In order to increase the density one could also use powder or grains of uranium or uranium compounds and compress them, or make such substances melt, these means being only exemplary.

It has been seen above that a certain number of critical conditions must be realised in order to make possible the working of the apparatus for the production of energy.

Amongst these conditions is the determination of the critical mass and, furthermore, of the configuration of the apparatus; there are the diffusing elements, etc.

It is obvious that when the working of the device is started by initiating the reaction it will be useful to increase these conditions gradually to their critical values so that there will be a slow increase of temperature.

Preferably, all the means for starting and/or regulating and/or stopping the apparatus should be able to be operated by remote control or a retarded control.

In order to increase the effective number of neutrons introduced into the apparatus by rapid neutrons one could introduce an element (deuterium or beryllium, for instance) which by absorption of rapid neutrons can literate two or more netrons of smaller energy.

In order to maintain the operation of the device it might be necessary to introduce into the mass supplementary quantities of certain of its constituents the concentrations of which be changed by the working of the apparatus itself.

It remains to be seen how the liberated energy could be extracted and what will be in the future the industrial applications of the apparatus.

The liberated energy could be extracted in the form of heat by conductivity (by a contact between the mass and water to which the heat will be transmitted, for instance), or by convection (circulation of water or gas through the apparatus) or by radiation or by realising endothermal chemical reactions in the interior of the mass.

The substance used for the extraction of heat out of the apparatus could at the same time have the function of the whole or a part of the substance used for slowing down. It could also be used as a carrier for the introduction of all, or some of the substances acting upon the operation of the apparatus.

A certain supplementary quantity of energy could be produced and made use of by absorbing all or a part of the radiations emitted by the apparatus (neutrons, electrons, X-rays, γ-rays, etc.) in specially selected substances and particularly in those forming the envelope.

However, these extracting means are not indicated in a limitative way.

The device will also provide the possibility of obtaining high temperatures susceptible of many applications.

It is, however, possible still to use it for other applications.

As a matter of fact, the extraction of energy causes the emission of considerable quantities of radiation (for instance X-rays, γ-rays or neutrons).

Whilst these radiations are dangerous and make it necessary to have some protection (water screens) around the whole or part of the apparatus, they can be used, on the other hand, for very interesting applications, especially for medical purposes.

Finally, the by-products which the apparatus will produce should be nemtioned. They will be due to the fact that new substances (such as radio-active iodine, potassium, rare isotopes or mixtures of isotopes in anomalous proportions, etc.) will appear in the mass as well as in the screens, and in the external envelope.

Thus, the elementary composition of the mass will slowly change until eventually the reaction will cease, the by-products will then have to be removed.

In every part of the apparatus disclosed above, the uranium may be totally or partially replaced by thorium.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. Apparatus for the production of energy by nuclear fission comprising a mass of uranium or thorium capable of giving rise under the action of neutrons to the emission of new neutrons in a chain reaction, the said mass comprising in a homogeneous or heterogeneous distribution deuterium (in an elementary or combined state) or helium in a quantity sufficiently high to reduce the velocity of a

proportion of said new neutrons to below the range of resonance velocities with respect to uranium or thorium, the proportion of deuterium or helium with respect to uranium or thorium being such that $n\frac{P}{A}>1$ (n, P and A being as defined), means being provided for subjecting the mass for initiating the operation to the action of neutrons generated in or outside it and means for carrying the heat developed therein outside the mass.

2. Apparatus as claimed in Claim 1, comprising a surrounding casing formed of substances having low absorption and high reflection properties with respect to neutrons, such as iron or calcium carbonate for instance.

3. Apparatus as claimed in Claim 1 or 2, in which the reacting substance, uranium or thorium, is used in a form in which it has the highest possible density, for instance compressed powdered metal or compound, or in the massive metallic state.

4. Apparatus as claimed in any of the preceding claims, in which means are provided for the circulation of heat exchanging fluid, through the reacting mass.

5. Apparatus as claimed in Claim 4, in which deuterium, in elementary or combined form or helium is carried by or forms the heat exchanging fluid.

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